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Technical Report No. 131

REPORT ON QUALITY AND POTENTIAL USE OF AUTOSAT-2 SST DATA

by

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NOVEMBER 1994

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1. INTRODUCTION

For several years a daily sea surface temperature (SST) analysis has been performed for the global NWP model. This analysis has then been interpolated first to the limited area grid and then in turn to the mesoscale grid. This has led to problems of unresolved points resulting from the interpolation having unrepresentative values and the inability to resolve fine detail structures which are important in the forecasting of sea-fog, convection etc.

Recently, a separate SST analysis for the mesoscale model has been developed and has now been implemented operationally, for development details see Jones 1993a. It is planned that this analysis will have the detail of fine structures that is currently absent from the existing global analysis. As well as being important for weather forecasting, this analysis also has potential commercial uses such as in fishing operations.

However, the mesoscale SST analysis currently can only use the same observations used by the global analysis, ie. ships and buoys. These observations do not have the spatial resolution required to resolve the fine detail that is required in the mesoscale analysis. The AVHRR (advanced very high resolution radiometer) on board the NOAA polar orbiting satellites has the potential for providing the spatial coverage required. Daily AVHRR products are received from NESDIS in the US but these are only provided as one data value per 2.5 degree box. AVHRR data are also processed in-house by the Autosat-2 system and it is these data that have the potential spatial resolution required as values are produced one per model grid box. The Autosat-2 system is an enhanced version of the one described in Whyte et al (1991).

This data has been studied to assess whether the needs of the analysis, both in terms of spatial resolution and in quality, are met. This report gives the results of this assessment and proposes how the data may be included in the analysis.

2. CURRENT STATUS OF MESOSCALE SST ANALYSIS

The mesoscale SST analysis runs daily using the same observation file as the global analysis but naturally using only those observations that lie within the mesoscale area. The distribution of observations for a typical day is shown in figure 1. It can be seen that observations are fairly widely scattered, especially away from the English Channel and North Sea. It is thus not surprising that the resulting analysis, shown in figure 2, does not resolve much detail.

THE AUTOSAT-2 PRODUCT

The Autosat-2 system processes AVHRR data from the polar orbiting satellites, currently NOAA-11 and NOAA-12. AVHRR pixels that are cloud free and over sea are mapped onto mesoscale model grid squares and a SST calculated using the standard 'split-window' equation[1]. A mean and standard deviation is then calculated for each grid square which has a reasonable number of clear pixels. These are then written to byte values in the final Autosat-2 product.

Each satellite makes four complete or partial orbits over the mesoscale model area each day and the data for each orbit is stored separately. Therefore, there may be more than one SST value available for each grid box.

In the analysis only data from those grid boxes classed as sea by the land sea mask will be used. Grid boxes near the coast will have some pixels over the land but these pixels should have been eliminated from the final mean. There are currently 5574 sea points in the mesoscale model, shown in figure 3.

AVHRR can only measure the skin temperature whereas the analysis is of the bulk SST and the difference between the two can be as much as 1K. However, the coefficients chosen in the split window equation and determine what bias, if any, is present in the data. The analysis scheme has a facility to correct for any bias that may exist in satellite data by comparing against in situ observations , Jones 1993b.

3. THE DATA STUDY

Autosat-2 data was collected for a total of 19 days between 10 May and 13 June 1994. The data were extracted in the middle of the afternoon as this is the time data extraction would occur in the operational suite. The data were compared objectively against the current operational mesoscale SST analysis, and subjectively against hand analyses drawn in CFO.

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[1]The split-window equation is

$$SST = \alpha T_{11} + \beta T_{12} + \gamma$$

where T_{11} and T_{12} are the 11μm and 12μm nadir brightness temperatures respectively and α, β and γ are the coefficients referred to in the text. As β is negative it is effectively utilizing the difference between the two channels which is a measure of atmospheric absorption.

The aims of this study were twofold; first to assess whether Autosat-2 data have the spatial coverage and resolution that is required by the mesoscale SST analysis and secondly to assess whether the data are of sufficient quality.

OVERALL RESULTS

Spatial Coverage

The total number of Autosat-2 products received for each of the days is plotted in figure 4. It can be seen that there is an average of about 12000 separate observations each day but this number depends heavily upon the amount of cloud. The cloudiness of the study period has not been assessed.

The total spatial coverage over the 19 days is plotted in figure 5. It can be seen that there is a large variation in the number of reports received in different regions. The most number of reports are in the northern North Sea with values near 120, indicating an average of 6 observations per grid box per day. This number decreases quite markedly as we move to the south west with only 10 to 20 observations received in this area. This can be explained partly by orbital factors, orbits converge as we move poleward and thus a greater number of observations will be available. However, there should be at least one pass from each satellite each day giving a total of about 40 observations in the 19 days sampled. There are probably also some synoptic effects, perhaps low cloud or sea fog in the south west approaches thereby reducing the availability of values.

As a comparison, the location of conventional observations is shown in figure 6. It can be seen that the majority of these observations are in the south west approaches, through the English Channel and into the North Sea. There are few observations to the west of Ireland. Although it is disappointing that there are not more Autosat-2 observations to the west of Ireland, it is still an improvement to the current situation.

There are a total of eight datasets representing the products from each of the 4 orbits of the two satellites. The total number of observations in each dataset is plotted in figure 7. There is a great deal of variation within each dataset, probably due to the daily synoptic situation and the average is about 1400 observations per dataset. Each dataset is overwritten by the corresponding orbit each day. Some of the variation between different datasets on the same day may be due to diurnal effects but these are not considered in this paper.

Data Quality

For this study, the observation minus SST analysis (O-A) values were grouped into 0.5 degree boxes. The overall graph is shown in figure 8. It can be seen that in general most observations lie between -0.5 and 1.0 of the mesoscale SST analysis and that 92% of observations are within 2°C of the analysis. There is a slight skew to the positive, due to the values of the coefficients in the split-window equation used.

4. CASE STUDIES

Details from a few selected days which highlight particular causes of concern are given below.

10 May 1994

The distribution of observations received on this day is shown in figure 9. It can be seen that the majority of observations are in the North Sea with the greatest number being in the far north east of the area. This is typical as could be inferred from figure 5.

Figure 10 shows the number of observations in each half degree observation minus analysis box, the shading represents different orbits. The distribution is approximately Gaussian but on this day there is rather more of a positive tail. In fact there are 1101 observations that are more than 2°C warmer than the analysis, 9% of the observations received on this day. Figure 11 shows observations from one orbit of NOAA-11. It can be clearly seen that there is a positive bullseye in the center of the North Sea, with temperatures of about 12°C, 4°C warmer the analysis (not shown). Out of the 8 orbits, 7 have data for this area. Of these 4 show a similar feature, two from each satellite.

Whereas this is the type of feature that it is hoped Autosat-2 data would resolve, it is felt that on this occasion this particular feature is not real, or at least if there is a warm eddy it is not of this magnitude. It is rather worrying that this error is present in four separate orbits and even more worrying that the error is present in data from both satellites. Three of the four orbits are in the late afternoon but one is in the early morning which suggests that it may be more than just atmospheric effects. There is no evidence of the feature in data from the following day. Figure 12 shows the SST values from the conventional observations received on this day. There are two observations in the vicinity of the bullseye which do at first suggest the present of a warm eddy. However, these must be treated with caution. The value of 8.5°C is from a moored buoy

which has failed the superob tests and the value of 9.7°C is a NESDIS AVHRR (NOAA-11) product.

Whatever the reason, this day highlights the necessity of having strict quality control in both the Autosat-2 processing system and in the subsequent NWP data processing system.

12 May 1994

Two orbits are highlighted from this day. First an orbit from NOAA-12 shown in figure 13. This orbit shows a very good spatial resolution, covering practically the whole area except for the area to the south west of Ireland. This orbit is a good example of the extra data that Autosat-2 should provide.

The second orbit from this day is shown in figure 14. This orbit shows a problem around the coasts. Along the East Coast of England there is a narrow band of temperatures about 3°C cooler than expected and along the north coast of the near continent there is a narrow band of temperatures 3°C warmer than expected. There is clearly a problem of coastal contamination in these two areas, either land pixels are not being correctly identified, the presence of cloud or sea fog that is not being identified, the sensors on the actual instrument not adjusting quickly enough to the different surface type or a navigation error in the satellite processing system.

6 June 1994

The overall statistics of O-A for this day are shown in figure 15. It can be seen that as well as the normal distribution around zero there is a peak at -3°C resulting primarily from two orbits. The Autosat-2 observation values from one of these orbits are shown in figure 16 and the difference from the analysis shown figure 17. There is a large area in the south west with values far cooler than expected. This may be due to the failure to distinguish low level cloud or sea fog. The problem is seen again, although not as dramatically, in the next orbit (not shown).

Autosat-2 observation values from an orbit later that day are shown in figure 18. There are two things to note here; firstly the spatial coverage to the west of Ireland, normally the area with fewest observations, and secondly the actual values are close to what is expected. This is so particularly in the area to the south west which had the cool values in an earlier orbit.

This particular day produced observations for practically the whole area as shown in figure 19.

5. DISCUSSION

The overall assessment of Autosat-2 data is encouraging. There are isolated problems, a few examples of which have been highlighted above, but with careful quality control the data can be used effectively.

Spatial Coverage

The spatial coverage is far better than at present although it is slightly disappointing to the west of Ireland which is also the area of fewest conventional observations. Obviously, the amount of data received in one day is highly dependent upon the synoptic conditions prevailing at the time.

Quality

There are examples of anomalously high or cool values and these are present in any observing system. Owing to the density of Autosat-2 observations it is not surprising that when one of these errors occur a great number of individual observations exhibit it.

The following table shows the potential quality control failure rate of Autosat-2 data compared with conventional data. The statistics for the conventional observation types are global.

	Number of obs received	Number of obs failed qc	Proportion of obs failing qc
Ships	39069	3605	9.2%
TRACKOBs	495	5	1.0%
BATHYs	963	37	3.8%
AVHRR(NESDIS)	62877	1001	1.6%
DRIFTERs	5624	625	11.1%
Fixed buoys	1809	478	26.4%
Autosat-2 (∓3.0°C)	224898	5589	2.5%
Autosat-2 (∓2.0°C)	224898	18260	8.1%

Notes:

Permanent rejects are not counted unless also failing quality control.
Drifters and fixed buoys are after superobbing.
The quality control limits for conventional observations are approximately 3°C difference from the analysis.

It can be seen that Autosat-2 compares quite favourably with ships, drifters and buoys. Even if the quality control limits for Autosat-2 are restricted to only 2°C then it is still better than other observation types. It is not surprising that relatively few NESDIS AVHRR products fail quality control as rigorous quality control has been performed on the product before it is issued.

The 3°C limit for conventional observations is rather arbitrary and a more stricter limit may be imposed in the future.

It was noted earlier that Autosat-2 seems to have a slight positive bias compared to the analysis. This is rather surprising since Autosat-2 measures the skin temperature and hence it is expected to have a negative bias compared to the analysis which is of the bulk SST. It has to be concluded that the coefficients used in the split window equation give this warm bias. Although it is not necessary to actually calculate the skin temperature, the coefficients should be examined and fine tuned to give a slight reduction in the value of the SST calculated.

Mesoscale Detail

The operational mesoscale analysis has been compared subjectively against the hand drawn SST chart issued by CFO for four days through the study period; 10 May, 18 May, 28 May and 13 Jun. This time of year sees a rapid warming of the waters around the UK due to the increased solar radiation and the relatively shallow waters. In the study period the warming in the North Sea was particularly rapid due to frequent, hot southerly airstreams.

The mesoscale analyses and the most appropriate CFO chart are shown in figures 20 to 23. It should be noted that the CFO charts are of the 5 day average of ship and buoy observations only and drawn to fit the observations exactly, something the mesoscale SST analysis is not designed to do.

10 May (figure 20)

On the 10 May CFO have drawn a 7°C isotherm much further south in the North Sea than the mesoscale analysis. Thus the mesoscale analysis is somewhat warmer than the CFO chart. These

tongue-like features, which can be either anomalously cool or warm compared to the surrounding area, are the type of feature that it is hoped to resolve using Autosat-2 data, this will not be known until Autosat-2 data are included in the analysis. Apart from that the two charts are in quite good agreement, both capturing the warm tongue to the west of Ireland, although there is more detail in the CFO analysis.

18 May (figure 21)

By the 18th May the warming of the North Sea has started in earnest. Both charts show a warming of between 0.5°C and 1°C over much of the North Sea from the 10th May, with little warming to the west of the country. Again there is more detail in the CFO chart. There is an area of warm water in the coastal waters of the Netherlands and Germany culminating in a 11°C isotherm in the Skagerrak where the mesoscale analysis only has 9.5°C. There is also a cool tongue in the Irish Sea which although the mesoscale analysis does hint at, it is not capturing the detail in the CFO analysis.

27 May (figure 22)

As time goes by the mesoscale analysis seems to warm more quickly than the CFO chart so that by the 27 May there is quite a difference over the North Sea between the two charts. The mesoscale analysis does now have the warm water along the coastal area described above.

28 May (figure 23)

By the 13 June the CFO chart is in much better agreement with the mesoscale analysis, although it does have a warm tongue in the central North Sea not identified in the mesoscale analysis.

This comparison shows that the mesoscale SST analysis does respond quickly to rapidly changing SST values even if it cannot resolve detail in the field. The CFO chart shows some extra detail but not as much as should be possible to resolve using satellite data. The CFO chart also tends to take ship observations at face value so some caution should be used although having said that, it is felt that the warm and cool tongues that are drawn are realistic, perhaps caused by a shift in wind direction. These features can last for a few days to over a week and are certainly important in the forecasting of sea fog or shower activity.

6. CONCLUSIONS

It has been shown that SST data from the Autosat-2 data does have the potential for providing the information required for a high resolution SST analysis in terms of both the spatial coverage and the quality of the data.

There is a slight warm bias in the Autosat-2 data probably due to the coefficients used in the split window equation or some other processing criteria. Although there are probably warm regions not resolved in the analysis, the consistency of the bias suggests this is not the main reason. The comparisons above show that the mesoscale analysis does respond quickly to rapidly changing SST, If the bias was due to a time lag between changing SST and the mesoscale analysis resolving the changes, then the bias would be seasonal. A further study in the autumn would be needed to confirm that this is not the case. There remains however, the fact that some tuning to the coefficients used should be investigated.

Contamination by low level cloud would result in a negative bias and although a few cases of this have been identified, it does not appear to be a widespread problem. There may be a problem with contamination of land pixels in coastal grid boxes, this could lead to either a negative or positive bias, but again this does not appear to be a serious problem.

In conclusion it is felt that with careful quality control and the use of the bias correction technique within the analysis scheme, good use can be made of the Autosat-2 data.

The next phase of the project is to test Autosat-2 data in the assimilation scheme. How this will be done and the quality control that will be used is described in the appendix A.

APPENDIX A. PROPOSED QUALITY CONTROL AND ASSIMILATION OF AUTOSAT-2 DATA

It is proposed to run a parallel mesoscale SST analysis using Autosat-2 data. This section describes how the data will be quality controlled, assimilated and statistics produced to verify the analysis.

Data Extraction

The data extraction will be performed on the HDS. There are eight datasets with Autosat-2 data which represent each orbit or partial orbit of each satellite, four from each satellite. Each of these datasets will be read and the extracted data written to another eight datasets.

The datasets containing the extracted data will each contain a header consisting of information extracted from the Autosat-2 header:-

Product identifier, histogram identifier, array of satellite id's, time last modified, observation times, number of rows in grid, number of columns in grid and number of grid boxes with data.

In the Autosat-2 dataset there are 53 entries per record and likewise there will be 53 entries per record in the extraction dataset. Each entry will consist of the following

x-coord y-coord SST byte value SD byte value % of clear pixels

The rest of the processing will be performed on the C90.

Quality Control

Conventional data is first reformatted into a data record, then quality controlled and then formatted again into an ACOBS file. Each process is performed by a separate program. This processing will not be performed with Autosat-2 data, instead there will be no data record creation and the quality control and ACOBS creation will be performed by a single program.

Each of the extraction datasets will be read into the program and the headers compared with a housekeeping file which will contain the last modification times of the previous day's files. If a dataset has not been updated then it will be ignored.

Next, the SST value will be compared against the background SST analysis value and those values which differ by more than some criteria (initially set at 2°C) will be rejected.

Next the standard deviation within the Autosat-2 product will be compared against a quality limit (yet to be determined) and those values exceeding the limit will be rejected. A similar check will be made of the percentage of clear pixels in the product.

The SST values which survive those tests will then be 'superobbed' so that at most there is one Autosat-2 observation per model grid box. This superobbing will consist of finding the mean of all Autosat-2 observations for a particular grid box. If there is excessive range (1°C) or standard deviation (0.5°C) in the products for a grid box then that grid box will be rejected.

Finally, all those Autosat-2 products that pass all quality control checks will be written to an ACOBs file.

Assimilation

The SST analysis program will be altered to have the ability of reading 2 ACOBS files, one containing the conventional data and one containing the Autosat-2 data. The assimilation will then be performed as normal and Autosat-2 data will be bias corrected. The bias correction scheme compares satellite data against in situ data and both a positive and negative bias in satellite data can be handled. It is envisaged at this stage that the quality control of Autosat-2 will reduce the data volumes sufficiently to negate the need of filtered increments or similar techniques for handling high density data.

Autosat-2 data will be assigned a model observation type of 41 and initially an observation error of 0.8°C.

Monitoring

It will be necessary to perform monitoring of the data to continually assess its quality and the impact upon the analysis. There are no plans to create an OPD or similar database for Autosat-2 data so monitoring will be performed by programs run upon the HP system. These monitoring jobs will be submitted automatically after the analysis has completed.

The extraction datasets, the analysis and the ACOBs files will be transferred to the HP. The previous days analysis, ie the background file, will also be on the HP so that O-B (observation minus background) and O-A (observation minus analysis) statistics can be produced.

Statistics that will be produced will be:

mean and rms of O-B for each orbit and in total (raw data)

mean and rms of O-A for each orbit and in total (raw data)
mean and rms of O-B of observations failed QC for each orbit and in total (raw data)
mean and rms of O-A of observations failed QC for each orbit and in total (raw data)
mean and rms of O-B of observations passed QC for each orbit and in total (raw data)
mean and rms of O-A of observations passed QC for each orbit and in total (raw data)
count of observations in each 0.5°C O-B band for each orbit and in total.
count of observations in each 0.5°C O-A band for each orbit and in total.
spatial distribution of raw data received.
mean and rms of O-B of 'superobs'.
mean and rms of O-A of 'superobs'.
spatial distribution of superobs

Another report will be issued at the end of the parallel trial.

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Jones, C.P. (1993a). 'Sea Surface Temperature Analysis for Regional Models'. Forecasting Research Division Working Paper No, 151. (Unpublished paper).

Jones, C.P. (1993b). 'Use of satellite Data in the Operational Sea Surface Temperature Scheme'. Forecasting Research Division Technical report No. 48. (Unpublished paper)

Whyte,K.W, Allam,R.J., Holpin,G. and Smith,F. (1991). 'The Operational Use of AVHRR Imagery products in the UK Meteorological Office'. Proceedings of the 5th AVHRR Data Users Meeting, Tromso, Norway, 25-28 June 1991.

Figure 1: Typical distribution of conventional SST observations (excluding NESDIS AVHRR) received in one day in mesoscale model area.

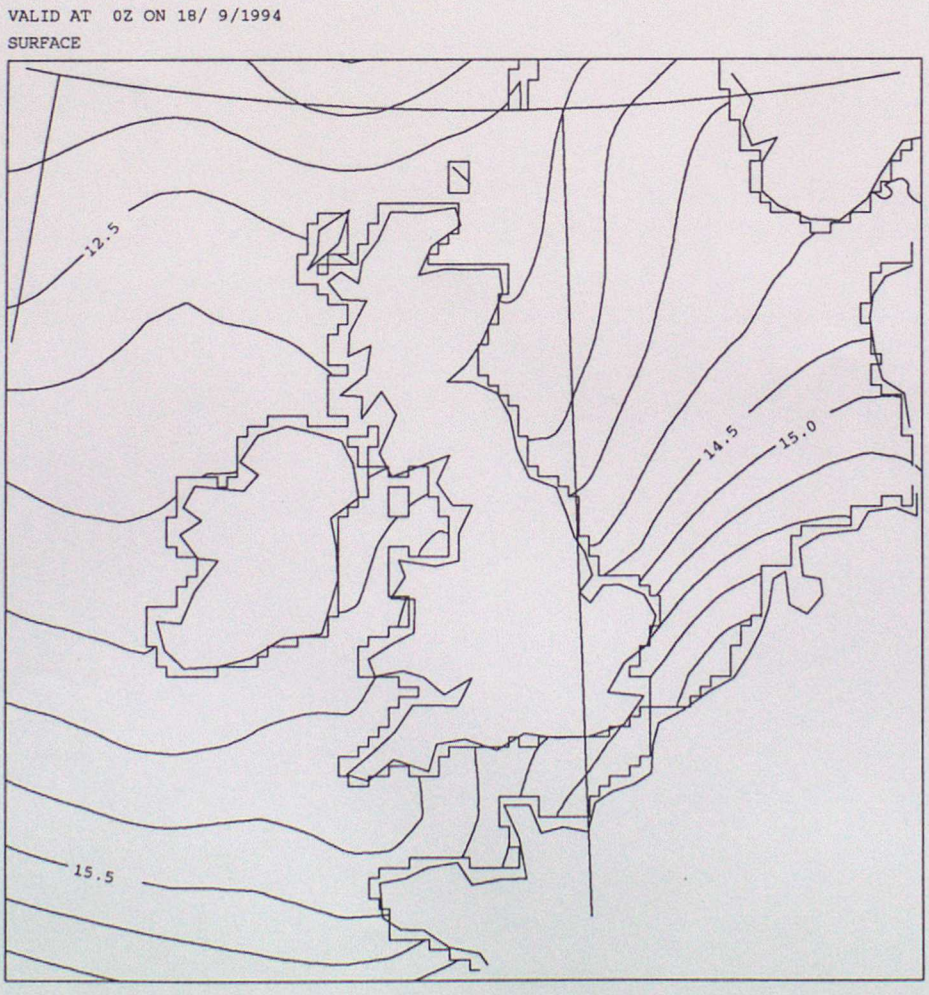


Figure 2: Example of current mesoscale SST analysis.

This might look better without the coastline and lat + long

Figure 3: Sea points in mesoscale model. Potentially, an Autosat-2 observation could be received at each of these points each day.

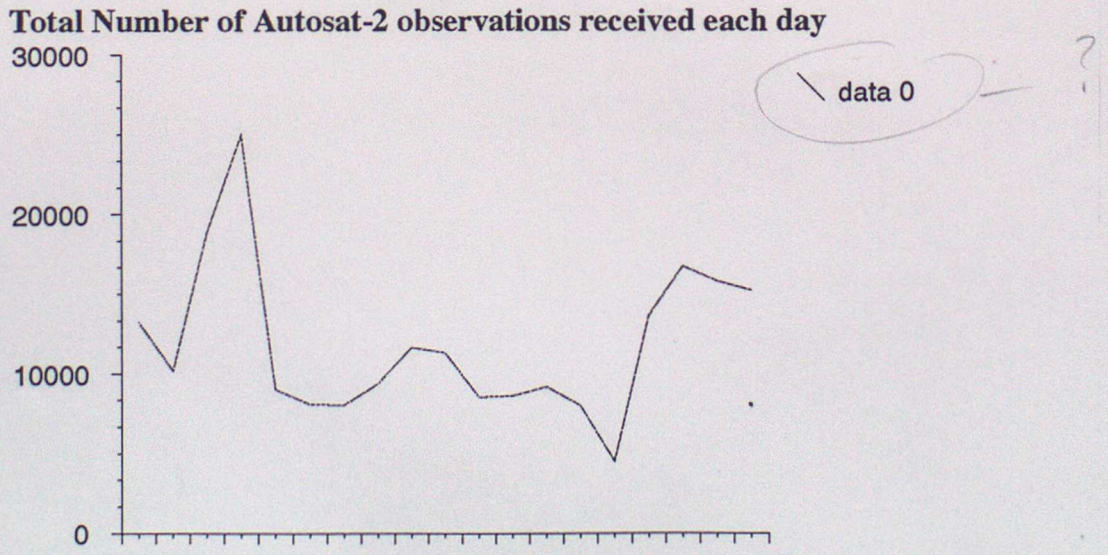


Figure 4: Total number of Autosat-2 observations received each day studied.

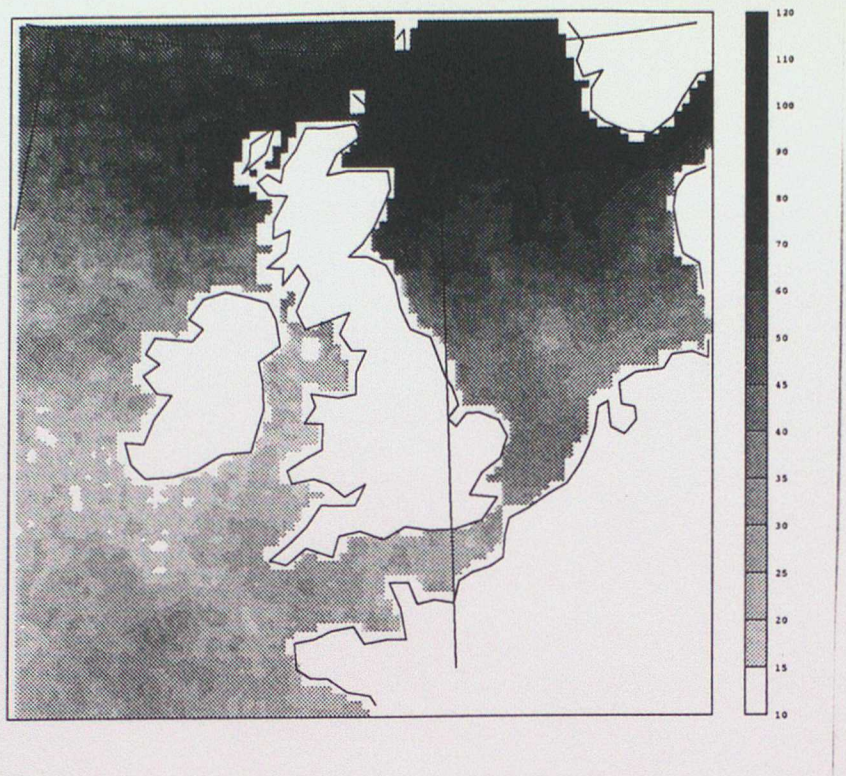


Figure 5: Spatial distribution of Autosat-2 observations received on the days studied.

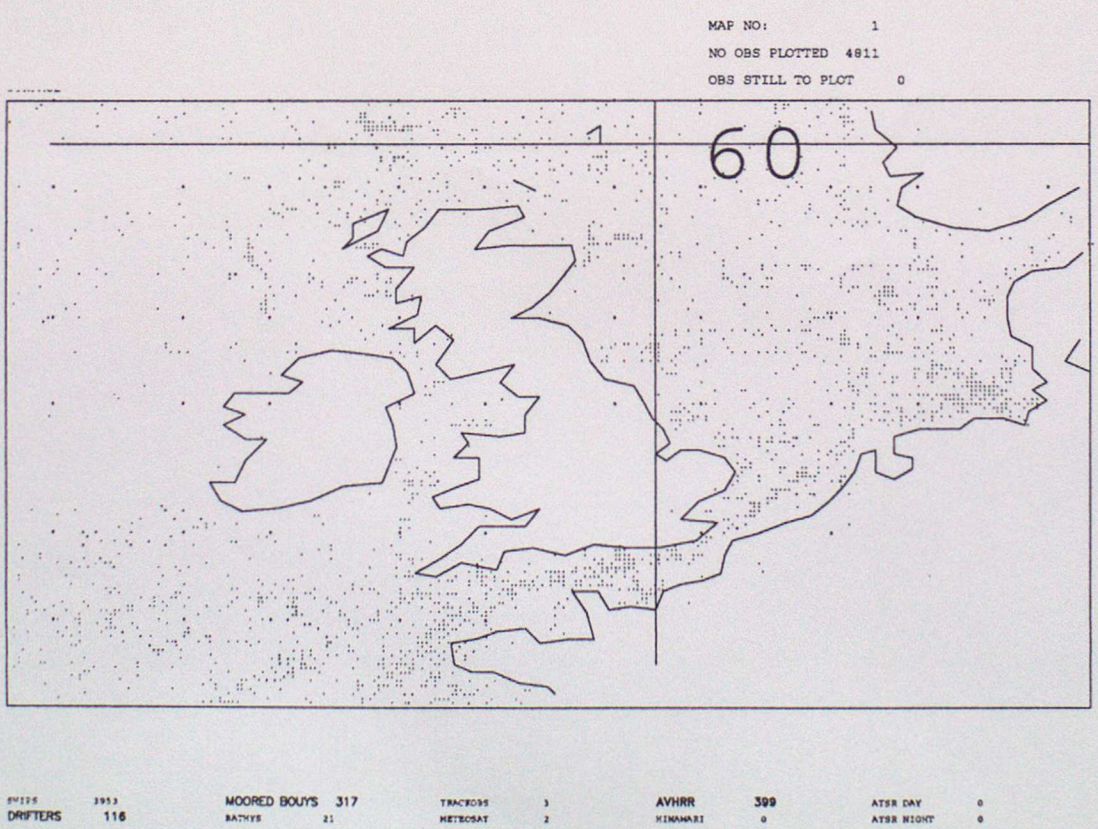


Figure 6: Distribution of conventional SST observations received on days studied.

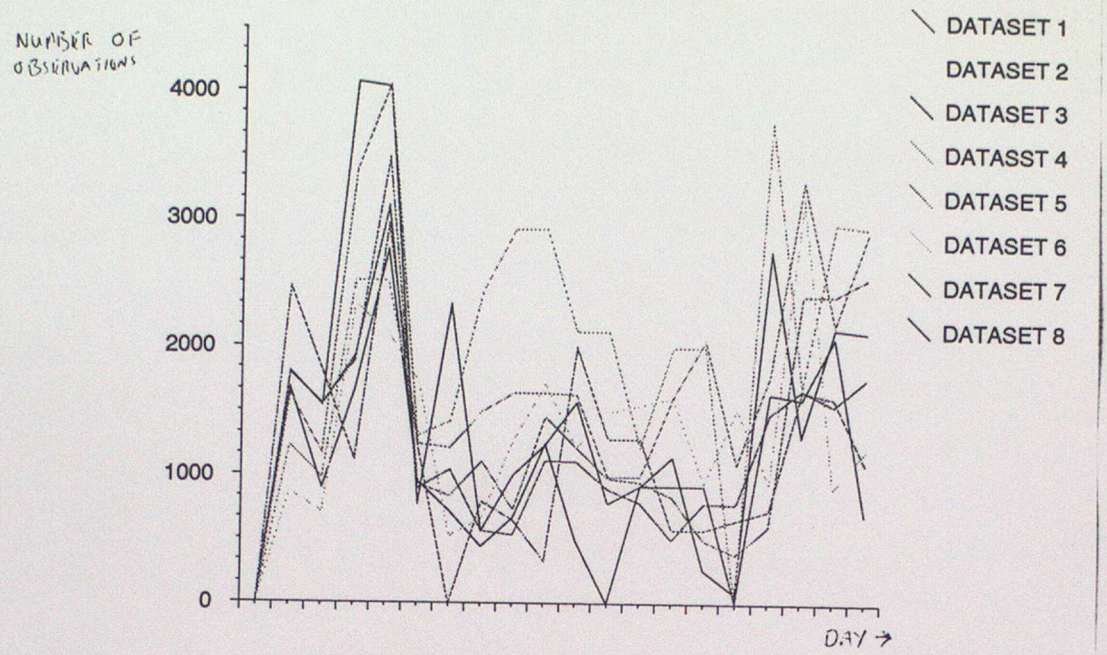


Figure 7: Total number of Autosat-2 observations received from each orbit on the days studied.

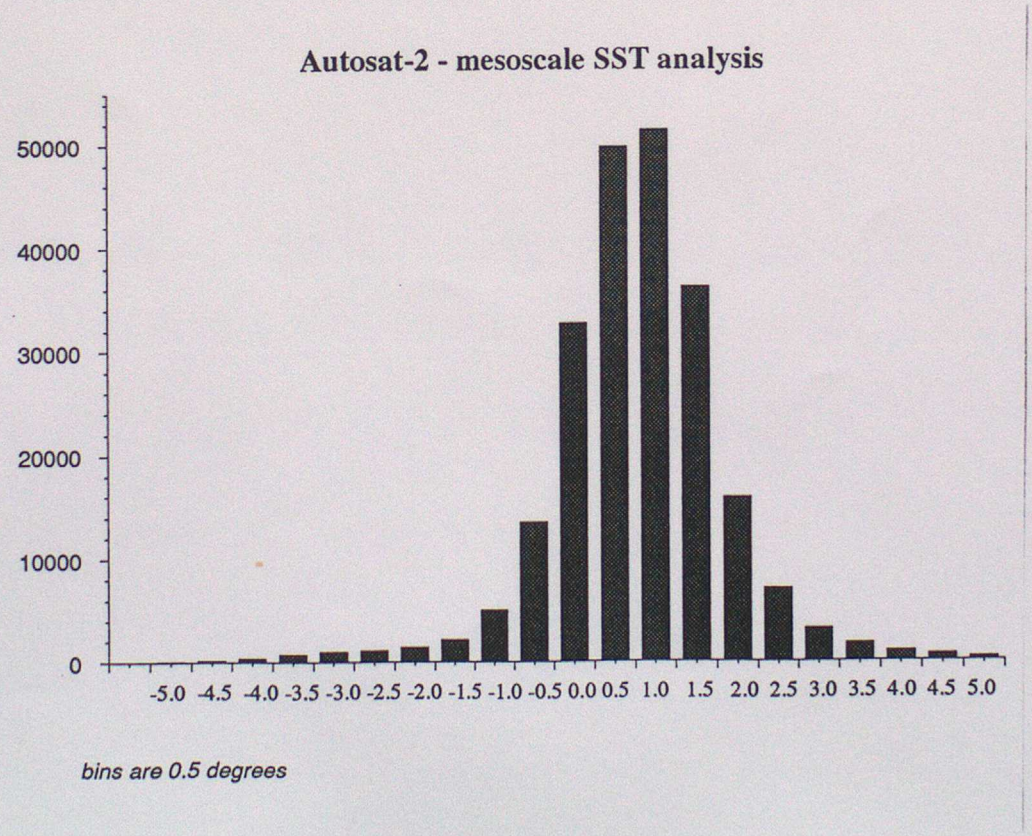


Figure 8: Plot showing the total number of Autosat-2 observations in each half degree bin of difference from analysis. The horizontal scale denotes the upper level in each bin.

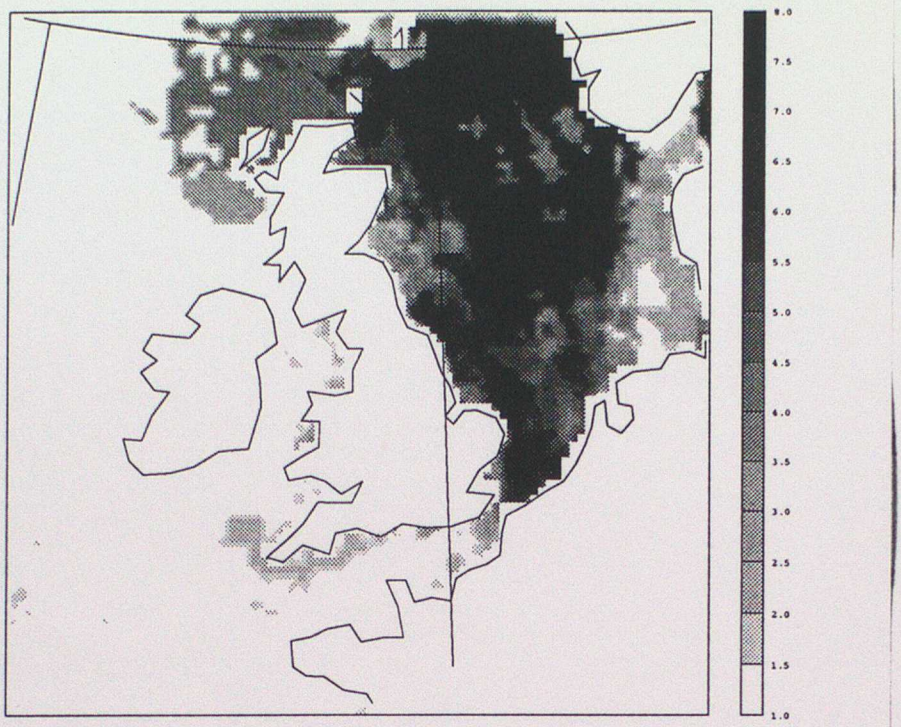


Figure 9: Spatial distribution of Autosat-2 observations received on 10 May 1994.

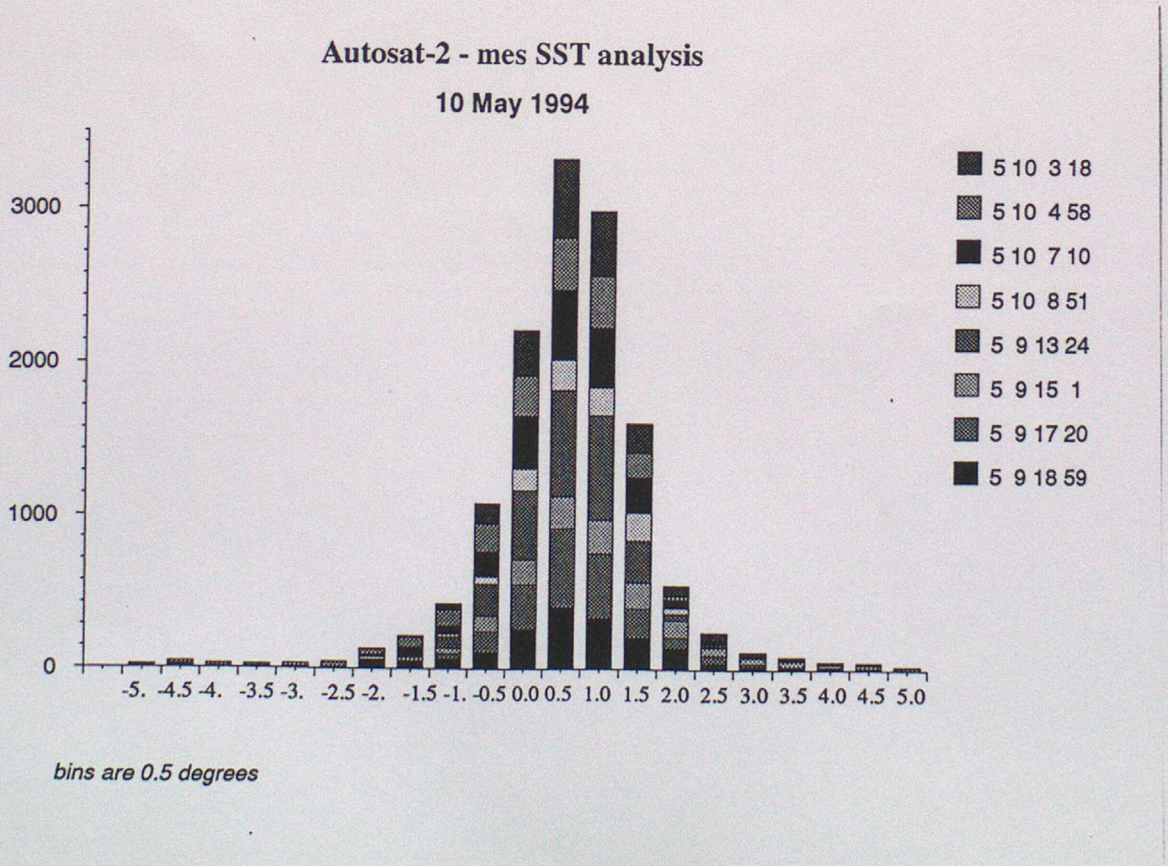


Figure 10: Plot showing the number of Autosat-2 observations received on 10 May 1994 in each half degree bin of difference from analysis. The horizontal scale denotes the upper level in each bin. The colouration indicates the different orbits.

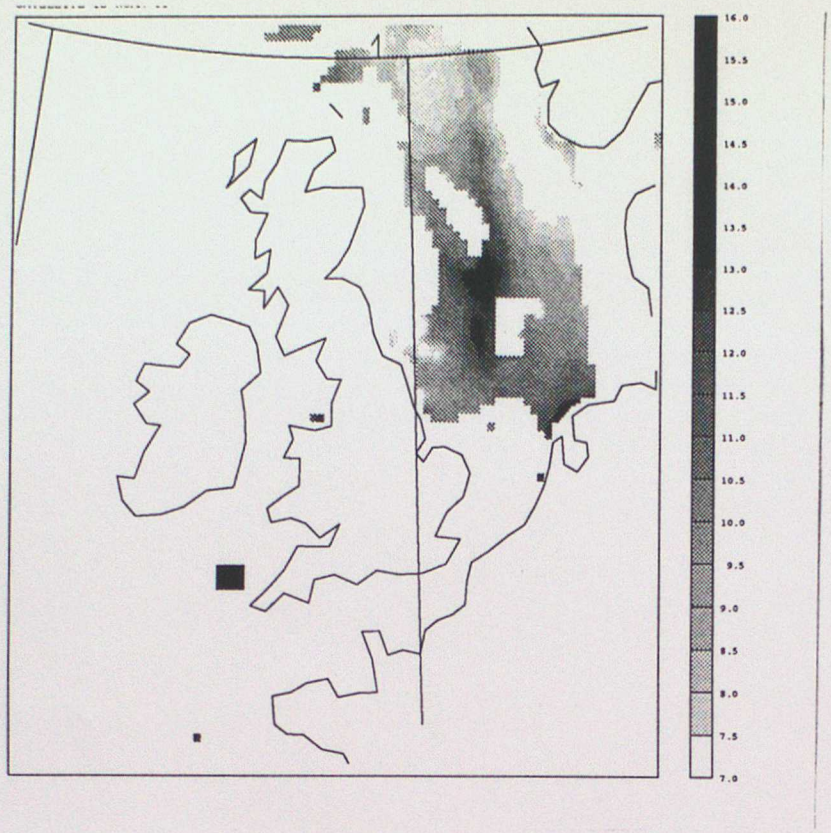


Figure 11: Autosat-2 SST values for one orbit received on 10 May 1994 showing anomalous warm eddy in southern North Sea.

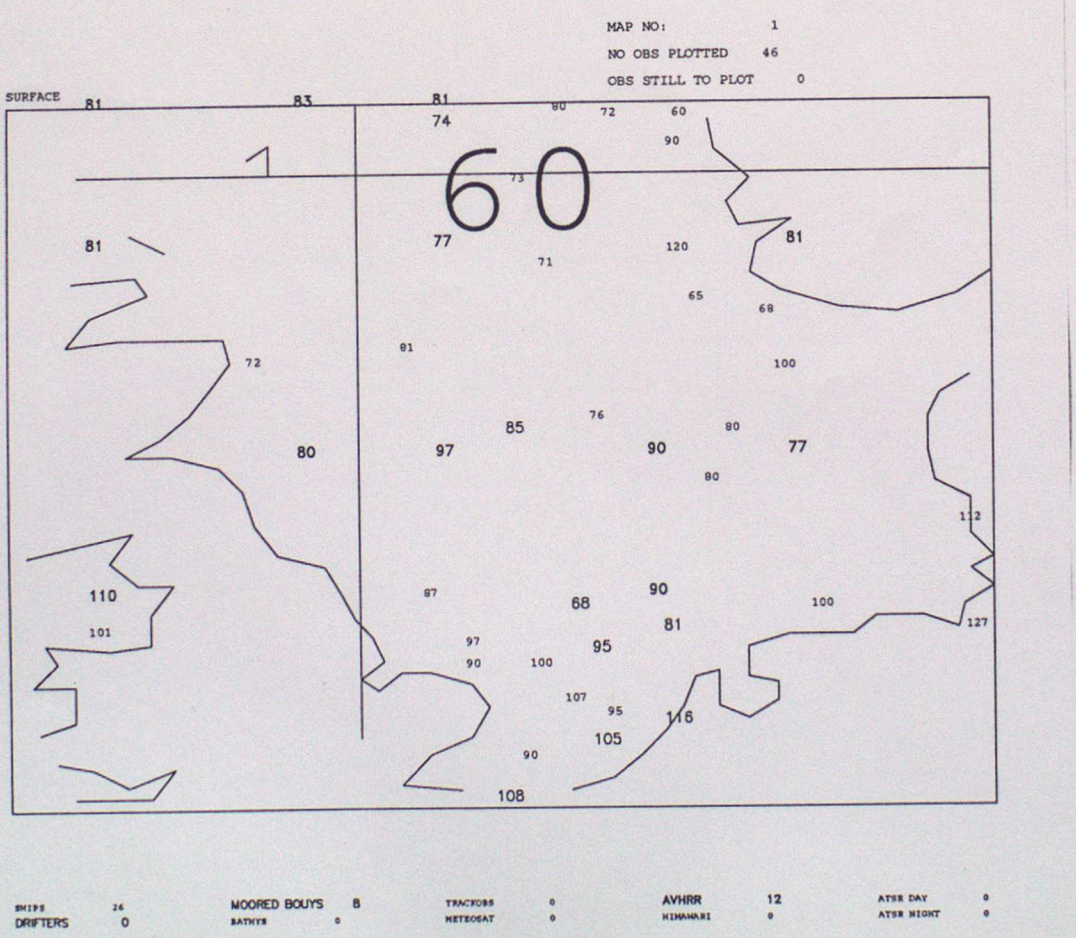


Figure 12: SST values observed by conventional data sources on the 10 May 1994.

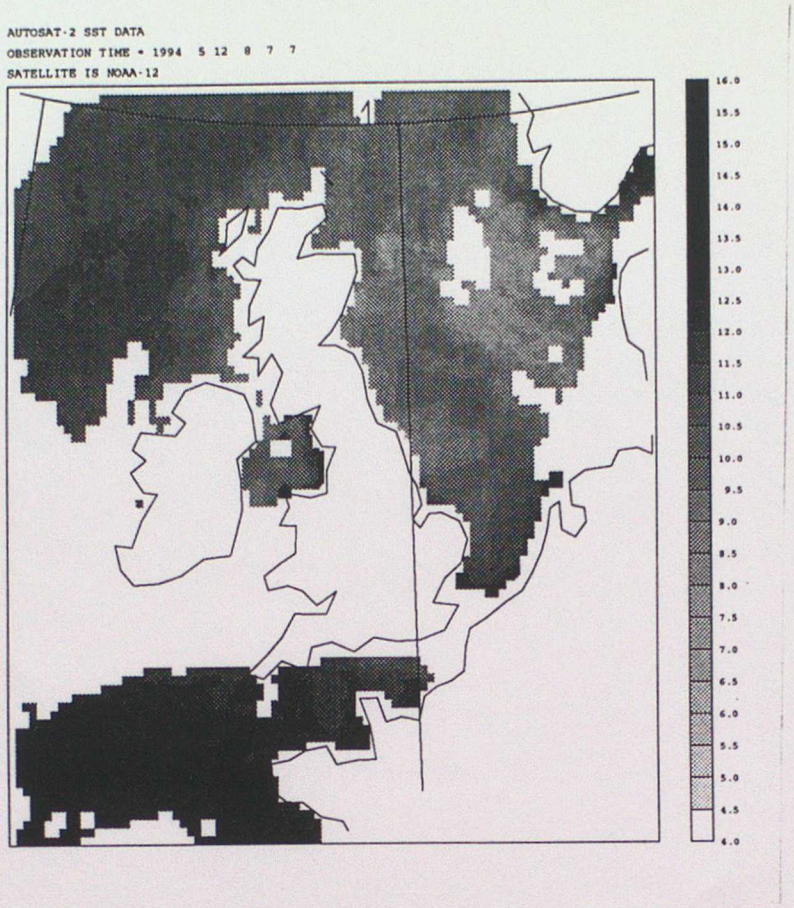


Figure 13: Autosat-2 SST values for one orbit received on 13 May 1994 showing the good spatial coverage that is expected from Autosat-2 data.

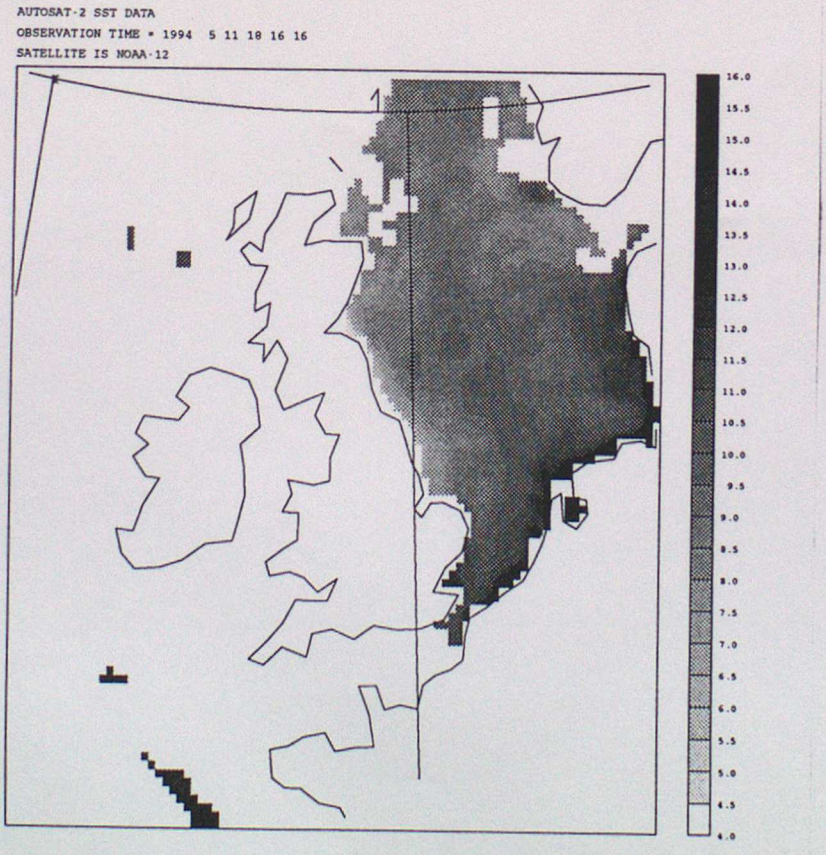


Figure 14: Autosat-2 SST values for one orbit received on 13 May 1994 showing anomaly cool values along East Coast and anomaly cool values along coast of near continent.

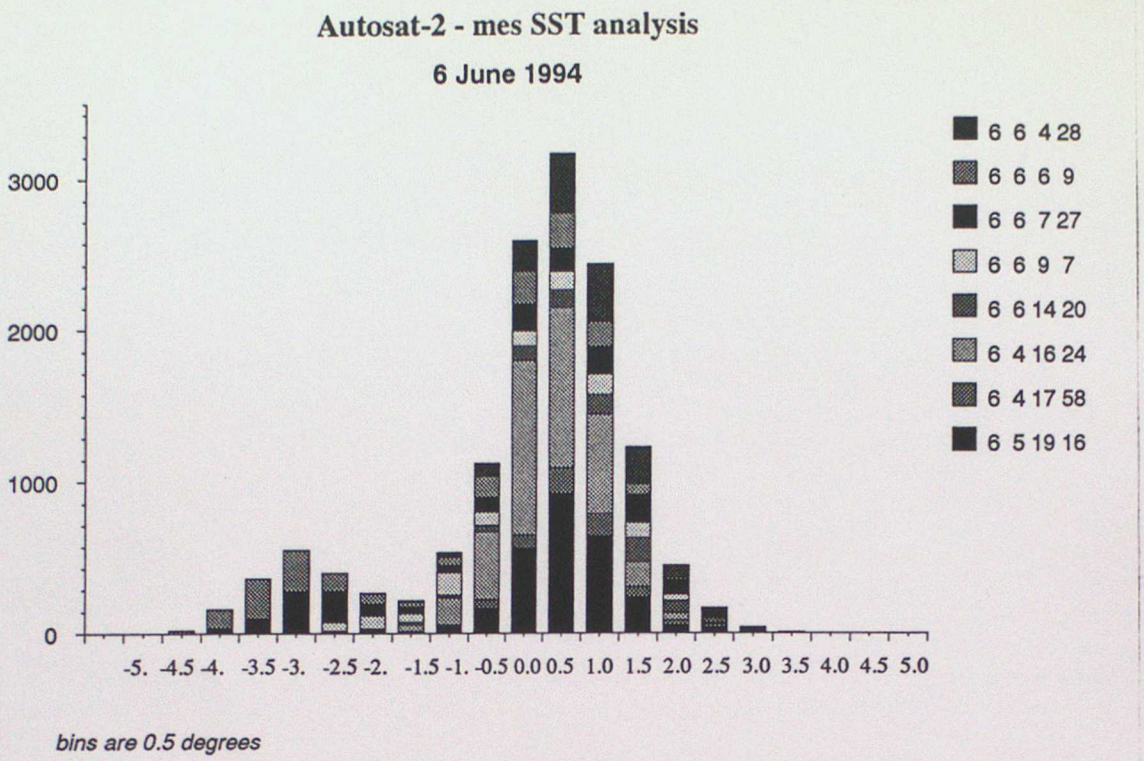


Figure 15: Plot showing the number of Autosat-2 observations received on 6 June 1994 in each half degree bin of difference from analysis. The horizontal scale denotes the upper level in each bin.

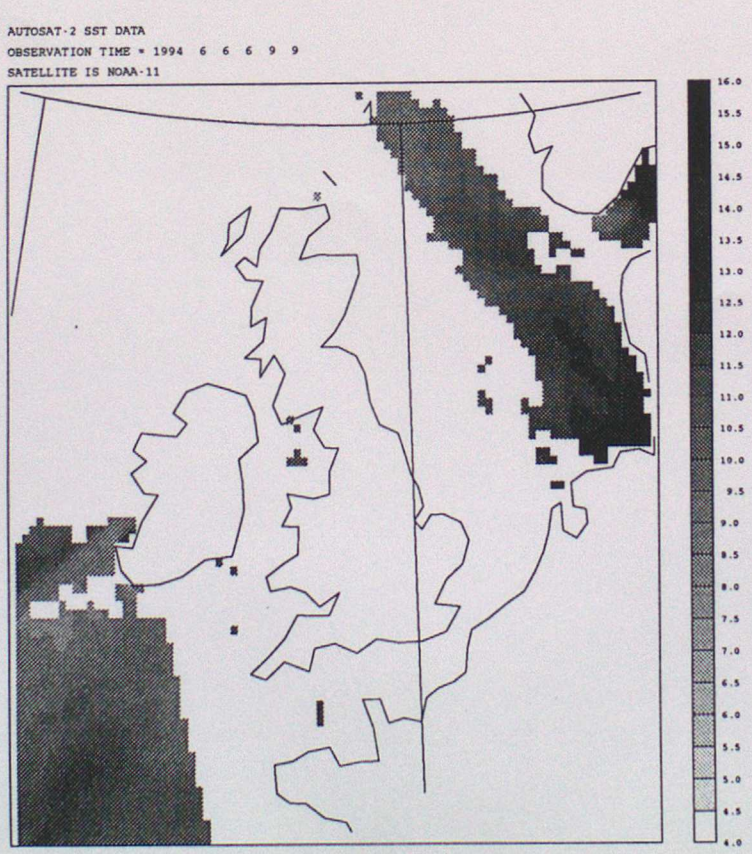


Figure 16: Autosat-2 SST values for one orbit received on 16 June 1994 showing area of anomalously cool values in south west of region.

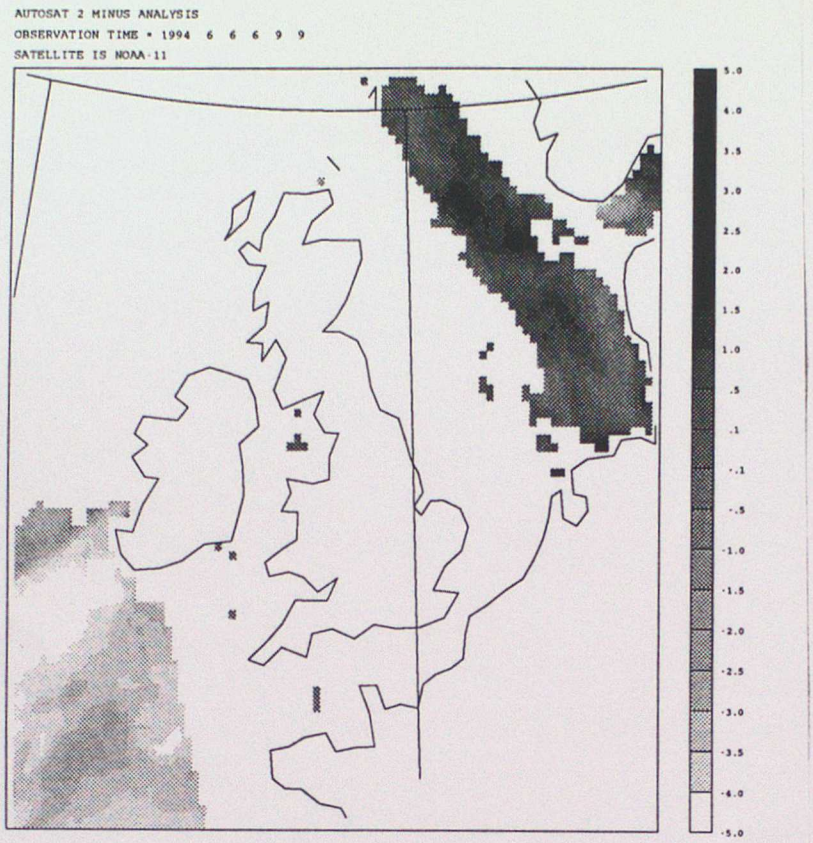


Figure 17: The difference of Autosat-2 and the analysis for the orbit shown in figure 16.

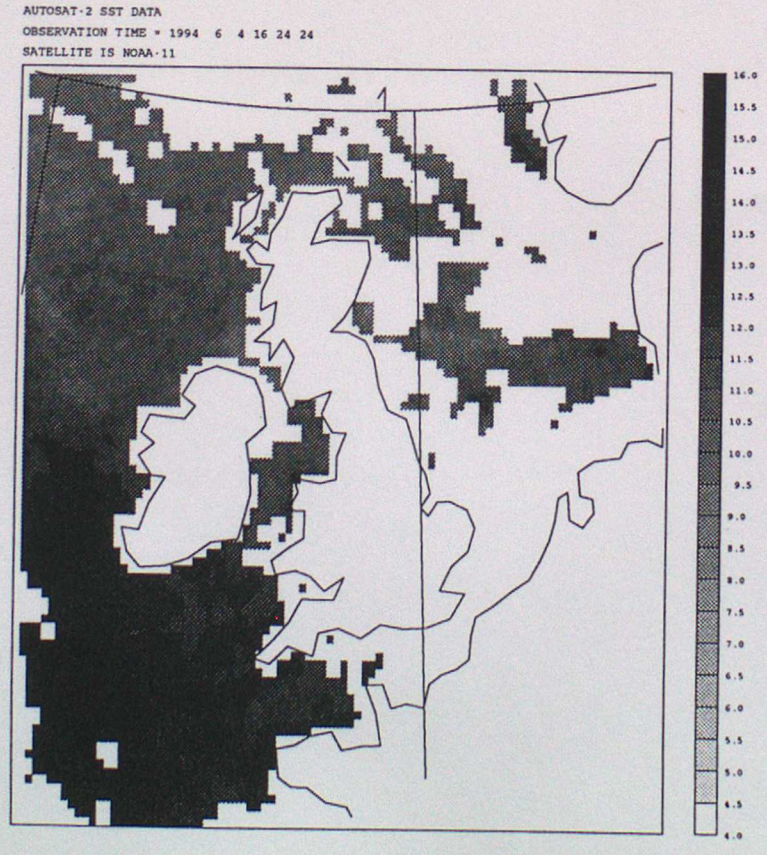


Figure 18: Autosat-2 SST values for another orbit received on 16 June 1994 showing more realistic SST values in south west.

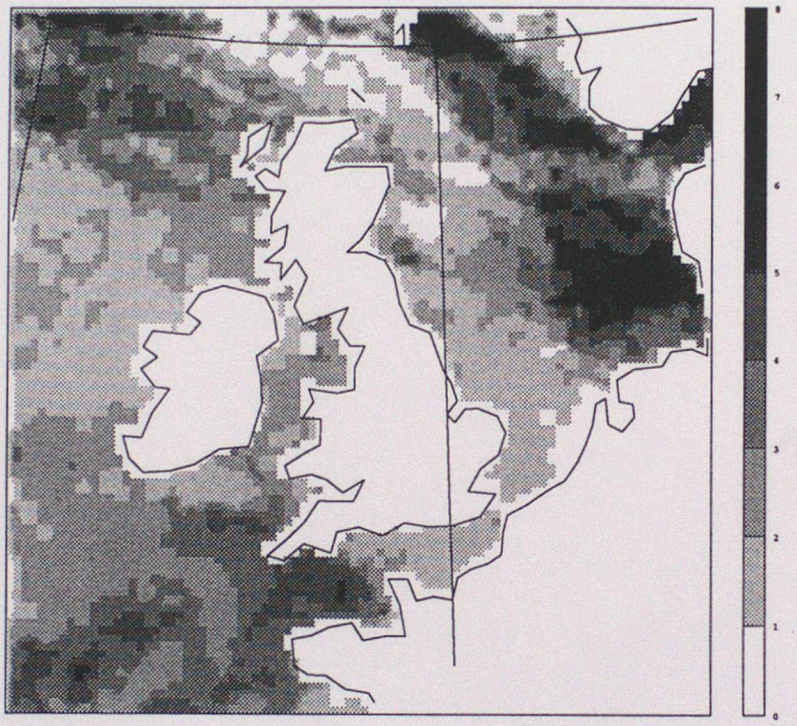
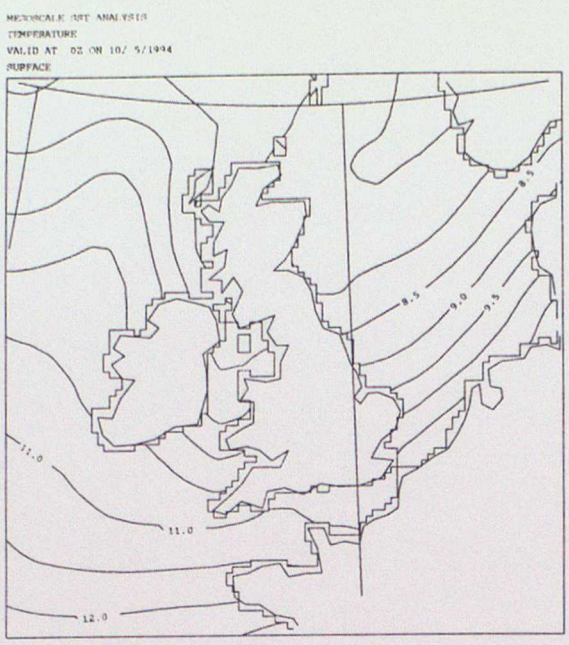


Figure 19: Spatial coverage of Autosat-2 observations received on 6 June 1994.



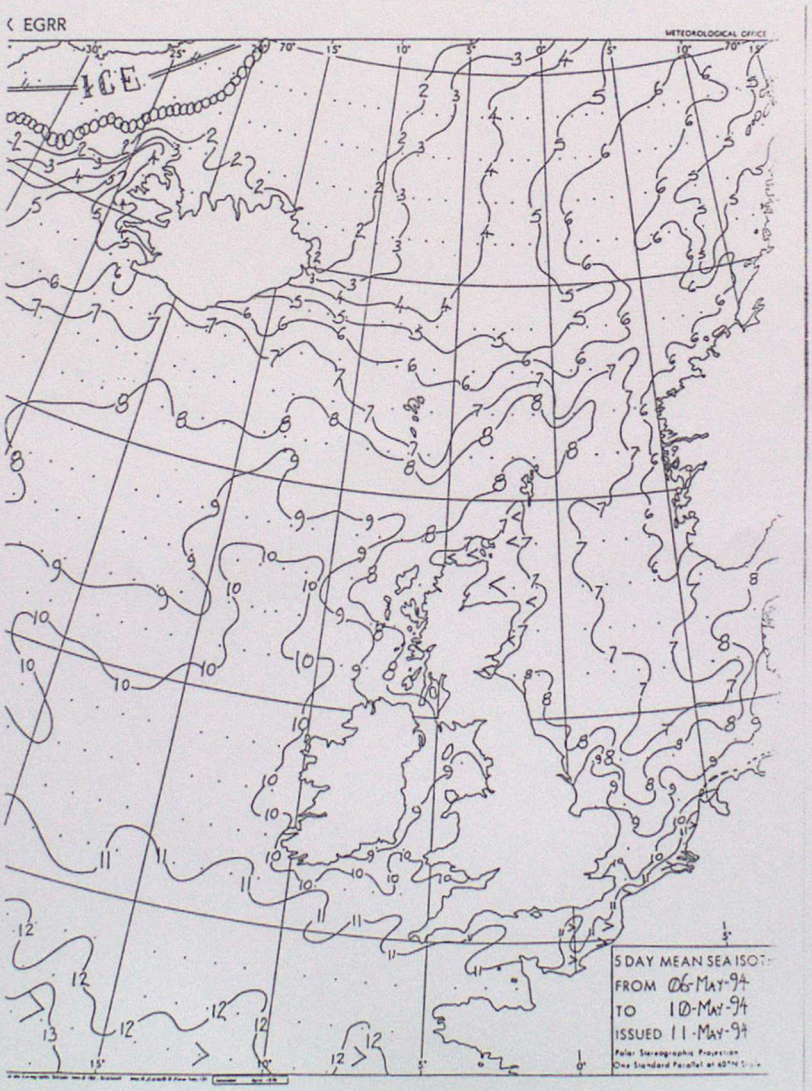
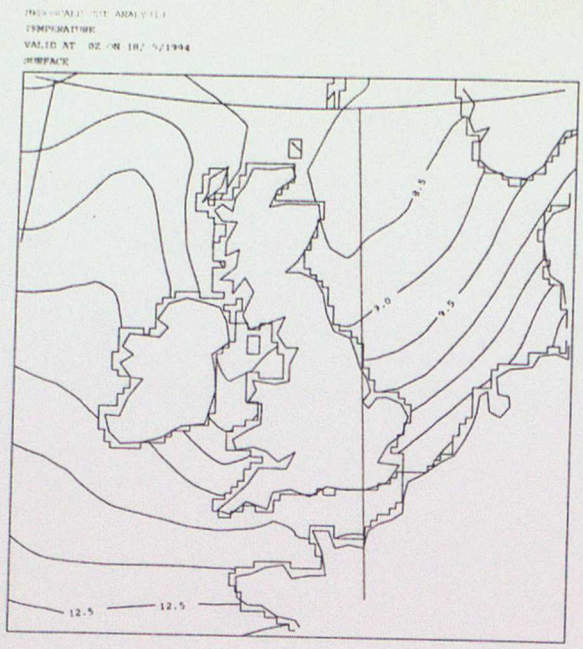


Figure 20: Mesoscale SST analysis for 10 May 1994, contours drawn every 0.5°C (top), and hand drawn SST chart issued by CFO on 11 May 1994.



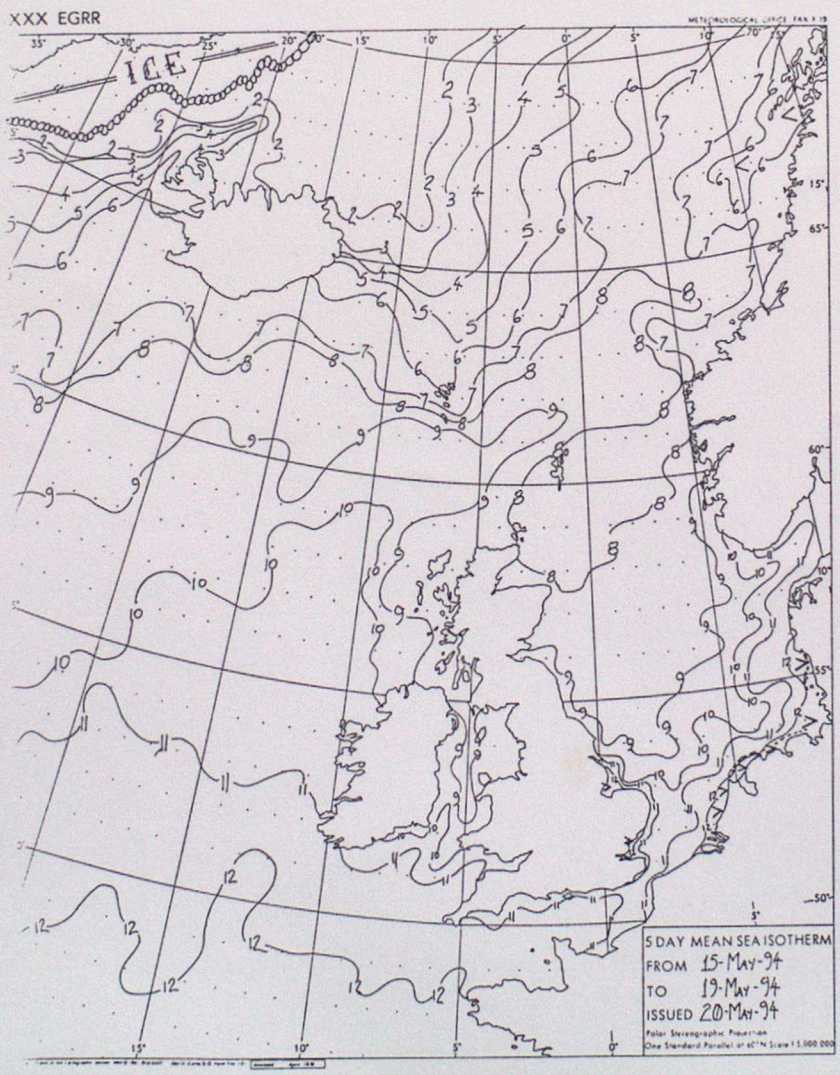


Figure 21: Mesoscale SST analysis for 18 May 1994, contours drawn every 0.5°C (top), and hand drawn SST chart issued by CFO on 20 May 1994.

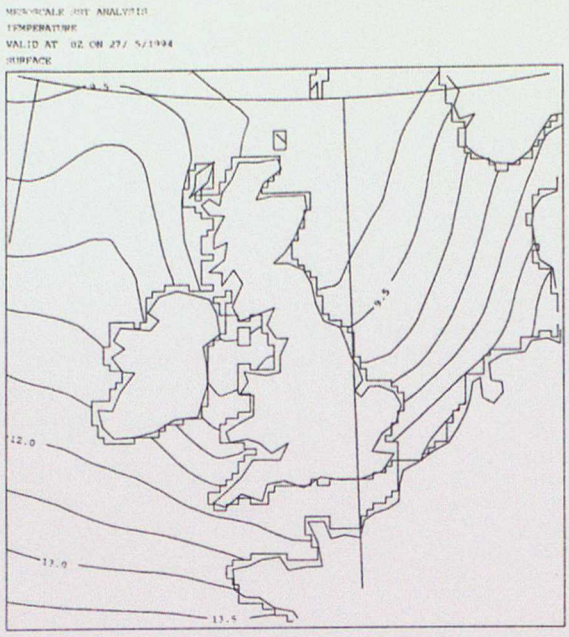
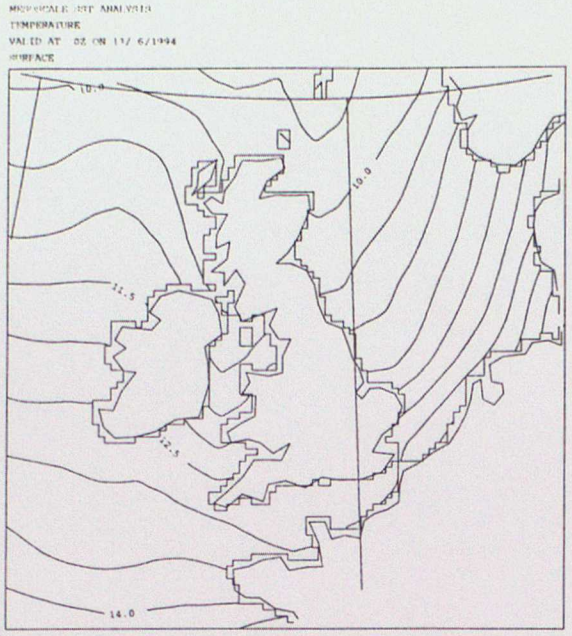


Figure 22: Mesoscale SST analysis for 27 May 1994, contours drawn every 0.5°C (top), and hand drawn SST chart issued by CFO on 30 May 1994.



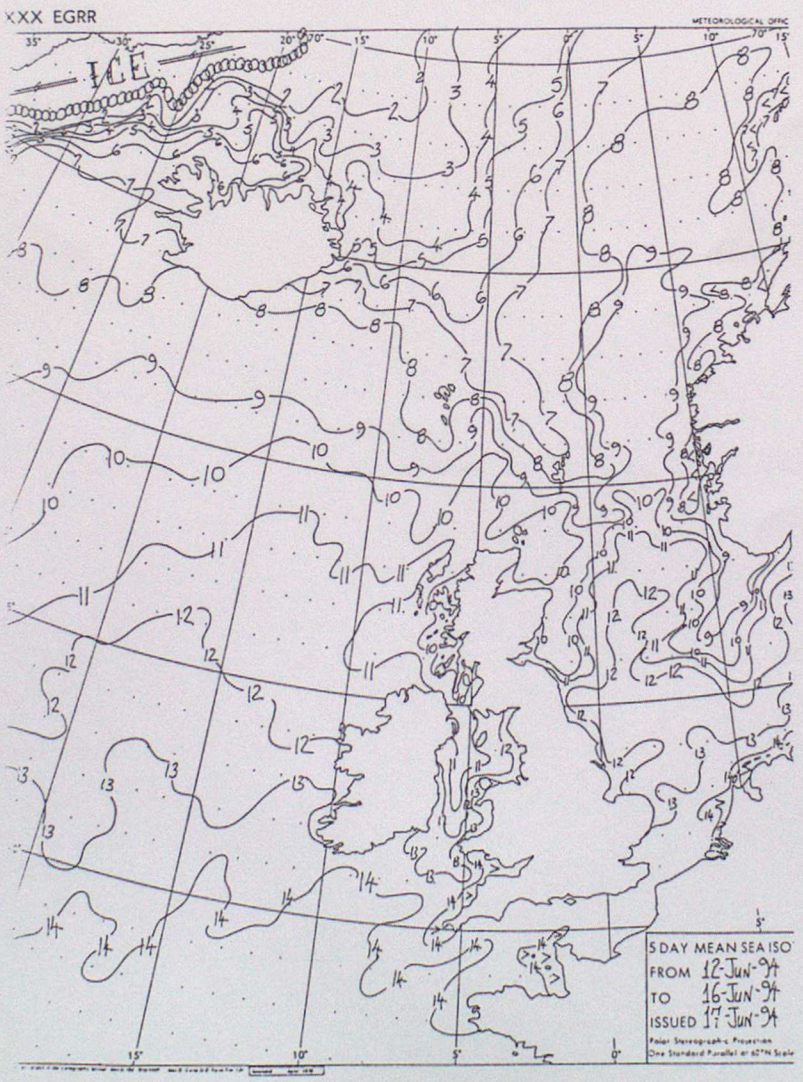


Figure 23: Mesoscale SST analysis for 13 June 1994, contours drawn every 0.5°C (top), and hand drawn SST chart issued by CFO on 17 June 1994.